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National Earth System Prediction Capability Project

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1. Background

The national Earth System Prediction Capability (ESPC) initiative arose from an agreement between DoD (Navy, Air Force) and NOAA leaders signed in 2010 to design and build the next generation global environmental analysis and prediction capability, covering time scales from days to decades. Due to the research needed, the effort was expanded in 2012 to include DoE, NASA, and NSF to improve communication and synergy for global prediction of weather, ocean, and sea ice conditions and for coordination of research-to-operations at weather to short-term climate variability timescales.

By coordinating efforts across agencies, ESPC hopes to develop a U. S. national research agenda that will lead to improved operational prediction across time scales. While acknowledging separate agency missions and requirements, this research agenda will encourage a common core capability based on common prediction requirements, interoperability, and forecast model standards; and lead to a global coupled air-sea-land-ice prediction capability based on multi-model ensembles.

In a series of articles in a special issue of the Bulletin of the American Meteorological Society, an international group of scientists put forth a strong argument for rationalizing investment in numerical prediction and accelerating capability to meet current and emerging requirements. Shapiro et al. (2010) calls for a holistic approach to NWP, linking observations, models, assimilation and analysis systems, and high-performance computing. Brunet et al. (2010) calls for a seamless weather-to-climate prediction system with special focus on the need for improvement of the representation of processes, particularly tropical convection, to improve prediction. The National Earth System Prediction Capability intends to meet these needs by fostering connections among the various modeling agencies and computing advances, taking a unified view across time scales.

2. National ESPC goals

The next-generation national operational environmental prediction system will use coupled model development to advance computational and environmental numerical prediction science and technology, and implement a computation suite across partner operational prediction centers. The system will use guided, focused process studies to enhance our understanding of the complex interactions of the earth environmental system that influence predictability at these longer time scales. The system will provide better quantification and display of uncertainty and forecast risk through probabilistic prediction techniques, and will improve assessments of predictive capability with better skill scores and metrics appropriate for the longer time scales. In this way ESPC's goal is to better inform public and private safety and policy decisions for the United States in an increasingly complex and changing global human enterprise.

3. Programmatic strategy

ESPC builds on the past successes achieved by interagency efforts. Notable among these successes is the Hurricane Forecast Improvement Program (HFIP) (Gall *et al.* 2013), which is providing rapid improvement in research-to-operations for both US (via NOAA) and global (via Navy) tropical cyclone track and intensity

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prediction capability. HFIP uses a distributed computing concept to leverage the resources of multiple agencies.

Another interagency success on which to build is the National Unified Operational Prediction Capability (NUOPC) (Sandgathe *et al.* 2011), which is using multi-model ensembles to improve medium-range (5-16 day) forecasts and provide probabilities of specific events. NUOPC also uses the distributed computing concept by combining the operational model output from several prediction centers to improve the medium-range capability.

ESPC also benefits from the National Multi-Model Ensemble (NMME) (Kirtman *et al.* 2013), which provides guidance out to 12 months using multi-model ensembles of climate models from both operational and research agencies and offices. NMME began as a proof-of-concept research initiative; even though the models are run at sub-optimal resolution leaving room for skill improvement with resolution, the project has quickly found a much-needed niche and will develop to better meet forecast needs over this time scale. Expanding on the other interagency efforts, NMME distributes computing and maintenance across not just operational but also research facilities.

In building the interagency "system of systems" ESPC will rely on existing collaborative community models to characterize parts of the earth environment. The Hybrid Coordinate Ocean Model (HYCOM) (Bleck 2002) and its data assimilation system have been developed to provide daily, weekly, and extended forecasts of global ocean conditions at high (~3km) horizontal resolution. WaveWatch III (Tolman *et al.* 2011) provides surface wave growth, decay, refraction and other properties of the wave fields. Both HYCOM and WaveWatch III are used extensively in academia for continued research. Additionally, the Los Alamos Sea Ice Model (CICE) was developed for coupling to various global and regional models, including those participating in the Fourth and Fifth Assessment reports of the Intergovernmental Panel on Climate Change. Land models such as NASA's Land Information System and NOAA's Noah Land Model permit partners to access the latest model improvements. The Naval Research Laboratory is in the process of integrating these models into a short to medium range (0-90 days) Earth system coupled prediction capability that has shown good progress in initial case studies and sensitivity tests (Metzger *et al.* 2014).

To improve coupling and sharing across component models, ESPC relies on the Earth System Prediction Suite (ESPS) common model architecture (Collins *et al.* 2005). ESPS is a collection of earth system component models and interfaces that are interoperable, documented, and available for community use. With a focus on coupled modeling systems across weather and climate scales, ESPS is intended to formalize code preparation for cross-agency use, establishing plug-and-play capabilities via the NUOPC interoperability layer and simplify toolkit code selection for the broader research community. By increasing interoperability, ESPS is intended to leverage the legacy investments from NASA, NOAA, NSF, DOE, and Navy.

4. Scientific strategy

a. Coupled Modeling

Coupling between Earth system components improves predictive skill across time scales. While this is relatively well established at climate scales and in highly forced mesoscale conditions such as in tropical cyclones, recent UKMO work[1] identifies ocean coupling as an important way to improve model fidelity significantly even in the 5-15 day time range. A recent National Academy Press study (NRC. 2010) elaborated on the importance of exploiting low-order modes and sources of predictability within the climate system, to create intraseasonal to interannual predictions of the weather-climate system.

For short range prediction, tropical cyclone intensity and track is dependent on upper ocean heat content, i.e. the temperature and the thickness of the near-surface warm layer, which either provides available heat to fuel convection, or curtails convection if wind-driven ocean mixing penetrates to deeper cold layers, bringing them to the surface. Weather prediction in the littoral and coastal zones depend greatly on air-ocean temperature contrasts for land-breeze, sea-breeze, fog and stratus phenomena; additionally the strong currents

[1] https://www.godae-oceanview.org/files/download.php?m=documents&f=130221160735-AbstractJohnsTopic3.pdf

and temperature gradients associated with western boundary currents such as the Gulf Stream or Kuroshio can enhance surface winds and seas particularly during cold air surges.

For medium range prediction, phenomena such as monsoon onset and intensity as well as monsoon breaks are dependent on the interaction of heat storage over the continent vs. the ocean. Active tropical convection regimes such as the Madden-Julian Oscillation (MJO) depend on the interaction of atmospheric dynamics and ocean properties. Outside of the tropics, blocking patterns in the jet stream produce surface heat waves, droughts, and neighboring regions of intense flooding. Also, intense polar low pressure systems share some similarities with hurricanes in that they derive considerable energy from the ocean heat source.

For long range prediction, interacting modes of the air-ocean system drive such phenomena as the MJO, el Nino-Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), the North Atlantic Oscillation (NAO), and others; these phenomena drive teleconnections affecting weather and ocean properties throughout the globe.

b. Multi-model Ensembles

Multi-model ensembles provide a practical approach to estimating and understanding forecast uncertainty due to initial conditions and observation errors, model formulation, and numerical uncertainties. Ensembles of a single model can reduce error due to initial conditions, but these single model ensembles are often over-confident (have a low spread) and may have persistent error modes and biases. By combining the ensemble results of several models, the community can reduce these errors, obtain a better assessment of uncertainty, and leverage the distributed computing resources of various agencies to obtain a larger total number of ensemble members.

c. Predictability Demonstration Projects

Model fidelity at these time scales is presently less than desirable for decision-making. To foster improvements, ESPC has established a set of five Demonstration Projects to focus and coordinate inter-agency research efforts and demonstrate the predictability (or causes of lack thereof) for five phenomena distributed across the air-ocean system. These five projects consist of:

1) Extreme Weather Events: Predictability of Blocking Events and Related High Impact Weather at Lead Times of 1-6 Weeks

2) Seasonal Tropical Cyclone Threat: Predictability of Tropical Cyclone Likelihood, Mean Track, and Intensity from Weekly to Seasonal Timescales

3) Arctic Sea Ice Extent and Seasonal Ice Free Dates: Predictability from Weekly to Seasonal Timescales

4) Coastal Seas: Predictability of Circulation, Hypoxia, and Harmful Algal Blooms at Lead Times of 1-6 Weeks

5) Open Ocean: Predictability of the Atlantic Meridional Overturning Circulation (AMOC) for Improved Weather and Climate Forecasts

The projects do not represent a complete set of phenomena necessary for prediction across time scales, but rather a distributed subset of separate (interacting) phenomena for which correct representation is a prerequisite for forecast fidelity. A goal of these projects is to improve model representation of these conditions and provide those model improvements to the operational and research modeling centers.

d. National Ocean Partnership Program (NOPP) project

Global earth system coupled modeling at extended time scales is computationally intensive, particularly as model resolutions and ensemble numbers increase. Emerging heterogeneous computational architectures such as NVidia's Graphics Processing Unit (GPU) and Intel's Many Integrated Core (MIC) show promise in meeting the computation need, although existing codes need to be optimized to fully exploit the architecture . A NOPP project on Advancing Air-Ocean-Land-Ice Global Coupled Prediction on Emerging Computational Architectures has been initiated in FY13. The selected projects focus on:

1) Accelerated Prediction of the Polar Ice and Global Ocean (APPIGO)
2) An Integration and Evaluation Framework for ESPC Coupled Models
3) RRTMGP: A High-Performance Broadband Radiation Code for the Next Decade
4) NPS-NRL-Rice-UIUC Collaboration on Nonhydrostatic Unified Model of the Atmosphere (NUMA) Coupled Models on Many- Core Computer Architectures

Further information on these projects can be found at http://coaps.fsu.edu/aoli/projects .

5. Summary: towards a National ESPC

Federal partnering between agencies has the potential to leverage the efforts of many programs to improve adoption of research breakthroughs from the wider community into the national operational capability. Previous interagency programs such as HFIP, NUOPC, and NMME have shown great benefit to operational national forecast skill over short, medium, and long range weather by both leveraging the research efforts of the agencies as well as exploring a paradigm of using distributed computing for operations.

The National ESPC project's goals are to leverage community models for transition from research to operations of regional and global air-sea-wave-ice coupled models; to foster adoption of ESMF standards through the ESPS initiative; and to extend and improve the multi-model ensemble approach flexible enough to meet sub-seasonal and seasonal timescales through an NMME capable of transitioning research to operations.

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